Assessment of thermal comfort and indoor air quality parameters in studio and classroom environment

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ANALYZING THE EFFECTS OF THERMAL COMFORT AND INDOOR AIR QUALITY IN DESIGN STUDIOS AND CLASSROOMS ON STUDENT PERFORMANCE

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Abstract: This study explores the effects of different ventilation modes on thermal comfort and indoor air quality in design studio and classroom and also investigates its associations with student performance. To achieve that purpose, experimental and subjective measurements are run in both studio and classroom environments, in Interior Architecture and Environmental Design Department at Bilkent University, Ankara, Turkey. CO2 concentration values, indoor air temperature and humidity values as the main parameters of thermal comfort and indoor air quality were measured in both winter and summer season under the three modes of ventilation: 1) without opening door and windows mode setting; (2) natural ventilation mode and (3) the mechanical ventilation, TROX school-air unit mode. Under these three different modes in both seasons, student performance was measured based on concentration and attention test results. Outcomes calculated in IBM SPSS 21 software separately for both seasons and three different ventilation modes. To sum up, experimental and subjective results have shown that the mechanical TROX school-air unit mode (mechanical ventilation mode) is the most satisfactory indoor environment in terms of standards in both seasons, where the highest grade of students' concentration and attention are obtained.

Keywords: Thermal comfort, indoor air quality (IAQ), studio, classroom, student performance.

1. Introduction

In recent years, thermal comfort and indoor air quality have become a well-known issues, which get most researchers' attention to improve interior living spaces. They get more importance in school buildings since poor indoor air quality (IAQ) might have potentially negative effects on student's health and performance. Young people spend a significant part of their day indoors. Most of the studies reported that poor indoor environmental quality in schools result in illness leading to student absenteeism, as well as adverse health symptoms, and decreased academic concentration and attention levels (Eide, et al, 2010, Fitzgerald, et al, 2010; Eliseeva, et al, 2013; Mendell, 2005). The main aspects of classroom ventilation are not only to decrease the risk of health problems among occupants and diminish their discomfort level, but also help to eliminate any negative effects on learning and productivity (Sarbu and Pacurar, 2015). Low ventilation rates in classrooms have been also associated with lower student attention and concentration. (Mishra and Ramgopal, 2015). The building and finishing material that can cause air pollution, and human odors produced by occupancies, are the two significant factors that lead to indoor quality unsatisfactory. Most of classrooms in higher education have still inadequate ventilation problems, cause occupant dissatisfaction. Especially, art classrooms and design studios, which required high activity type as personal parameters of thermal comfort. Different than the other IAQ studies, this study contributes to the scientific literature by investigating the relationship between performance and CO2 concentration levels in both design studios and classrooms in design education context.

2. Literature review on ventilation and CO2 concentration in schools

Ventilation plays an important role in maintaining IAQ. "IAQ is defined as the desire of humans to perceive the air as fresh and pleasant, with no negative impacts on their health and productivity" (Fanger, 2006, p. 3). Gasses, including carbon dioxide CO2, radon, and volatile organic compounds (VOC) are the variables that affect the indoor air quality. Sarbu and Sebarchievici (2013) claimed that many factors including thermal adjustment, control of internal and external sources of pollutants, supplying of acceptable air, occupant activities and preferences, and proper operation and maintenance of building systems have an effect on IAQ. Based on early studies, in 1913 the New York State Ventilation Commission was founded to ensure that ventilation requirements were met in public buildings. Lehmberg, Yaglou, and their colleagues (1930) conducted chamber experiments, in which body odour levels of occupants were considered as a factor for the ventilation rate levels. Results of this research showed that "8 L/s per person controlled these odors to levels that weren't objectionable to persons entering the space from clean air environments" (Lehmberg andYaglou, 1930). Fanger (1970) started to develop the first classic steady-state model for air-conditioning based on a heat balance model of the human body in 1970. Afterward, those rates were 2.5 L/s m^2 in offices and 7.6 L/s m^2 in public buildings including schools, which convert to 50 L/s per person in offices and 22 L/s per person in classrooms based on the default occupancy densities in ASHRAE Standard 62.1 (Persily, 2015). Persily (2015) concluded that 5 L/s to 7.5 L/s per person was the acceptable limit for university classrooms.

The study by Wargocki and Wyon (2007) showed that there is a positive relationship between ventilation rate and student performance in a classroom environment. A Swedish experimental study (2008) recommended an air-conditioned university building with a sufficient air exchange and for a better classroom indoor air quality and thermal comfort (Norback and Nordstrom, 2008). In classrooms, the source of CO2 is the student metabolic production causing the indoor CO2 concentrations to exceed outdoor concentrations. An average individual with a normal activity produces 20 litres (0.02 m3) of CO2 in an hour, so the density of the crowd in a classroom, which is closely related with the ratio of the number of students to classroom area, can affect CO2 concentration levels (ppm) in classrooms. Therefore, the 1000-ppm concentration of CO2 is acceptable level as the maximum level in an indoor environment (Bulut, 2012). Table 1 illustrates recommended ASHRAE values for operative and acceptable temperature, humidity and CO2 concentration.

Table 1: ASHRAE Standard, recommendation for IAQ indicators, (ASHRAE, 2013).

	Operative Temperature	**Acceptable Temperature**	**Humidity**	**CO_2 Concentration level**
Winter Season	22 °C	20-23 °C	30-65 %	1000 ppm
Summer Season	24.5 °C	23-26 °C	30-65 %	1000 ppm

Haverinen-Shaughnessy, Moschandreas and Shaughnessy (2011) examined hundred elementary schools in the Southwestern United States and found that 87% of classrooms (one classroom per school) had ventilation rates below 7.1 l/s per person, which is the minimum ventilation rate according to ASHRAE 62.1. Shaughnessy et al. (2014) found that classroom ventilation rates and students' academic achievement have a linear association within the range of 0.9-7.1 l/s per person. Stabile et al. (2016) evaluated the effect of natural ventilation and manual airing in six Italian classrooms during both winter and summer periods and concluded that the manual airing technique could not provide a minimum indoor air quality in cold seasons and student are exposed high CO2 concentration during the winter times. A recent study by Luther, Horan and Tokede (2018) measured the levels of CO2 in 24 classrooms in six different schools in Australia and found that air exchange rate, CO2 exhalation rate and the number of pupils are the most important parameters in predicting the relationships between student performance and CO2 concentration levels.

3. Research methods

3.1. Setting

Ankara, the capital of Turkey, is located at 39°57' N latitude, 32°53' E longitude. It has a continental climate; dry, hot summer and snowy, cold winter. Consistent with Turkish State Meteorological Service (2017), the winter average temperature in Ankara is 0.2°C and summer average temperature is 23.5°C so that range of temperature require especial precaution in design and maintained of the buildings. However, most of the school buildings have no sustainable and well-maintained heating and cooling units that are directly controllable by students and staff, and introduce outside fresh air (Bulgurcu, İlten and Cosgun, 2006).

3.2. Sample and Studio selection

Bilkent University, Department of Interior Architecture and Environmental Design were chosen as the location for the experiment. The chosen room is a newly furbished room, which is located on the first floor of the building. It has equipped with a school air ventilation unit. The room is 125.6 square meters and is a high ceiling (3.6 m) design studio with three window façades, which is an advantage for natural ventilation and a disadvantage for losing heat in winter season. The studio is furnished with 32 regular drawing tables and 32 adjustable chairs, one desktop computer, one projector, and wall-mounted display setting panels from sound absorption fabric material, which also serve to keep acoustic comfort as well.
Participants of the study are 3rd-year undergraduate students of Interior Architecture and Environmental Design Department, which are voluntarily chosen from third year design studio course as the studio environment and Sustainable Design for Interiors lecture course as the classroom environment (Table 2). In addition, both studio course and lecture course evaluation conducted at the same room. Therefore, the balance between density of student, size of the room, and the type of activity they have get importance.

Table 2: Number of participant in the study.

	Winter Season	Summer Season
Studio Environment	22	16
Classroom Environment	100	50

3.3. Procedure

This study used both objective and subjective parameters to assess the thermal comfort and IAQ of the experiment room. It is composed of two phases: the winter season phase and the summer season phase, which conducted on 2016-2017 academic year. Each phase has three experimental conditions, in every which both objective and subjective measurements of thermal comfort and IAQ are repeated. Figure 1 illustrates the main conceptual procedure framework of the study. Table 3 explains the dates of experimental measurements.

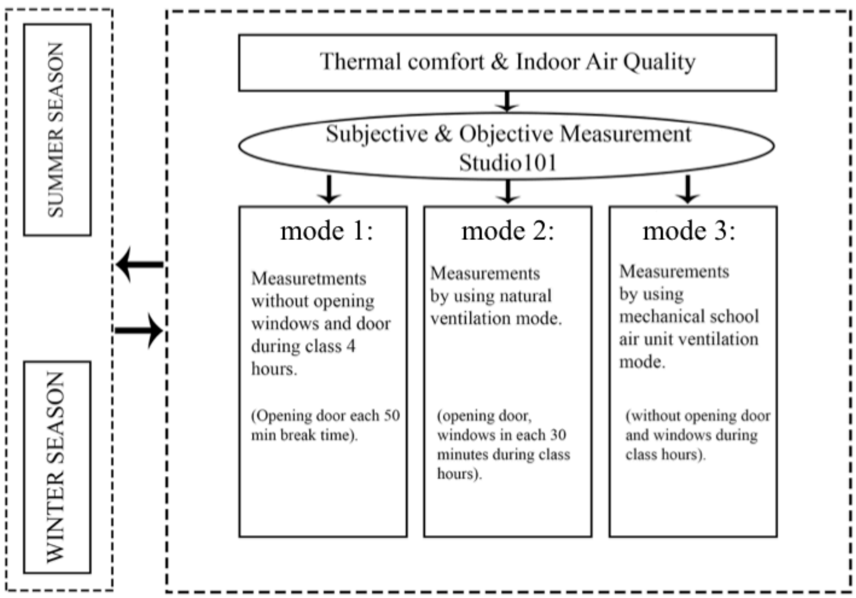

Figure 1: Main conceptual procedure framework of the study.

Table 3: Experimental measurement schedule on all settings.

	Winter	**Season**	**Summer**	**Season**
	Studio	**Classroom**	**Studio**	**Classroom**
Setting I	1Nov 2016	6Feb 2017	4April 2017	3April 2017
Setting II	15Nov 2016	20Feb 2017	18April 2017	17April 2017
Setting III	29Nov 2016	6March 2017	2May 2017	1May 2017

Setting 1 is a none ventilation mode, which means that during the class hours neither door nor windows are open, and ventilation is happened by the door and windows leak, except break times. This setting purpose is not only to identify how much energy we lost from old building, but also in winter because of not losing energy, manually ventilation is not happening properly. Setting 2 is a natural ventilation setting, which means that fresh air comes to space by opening the door and three cross windows in specific time periods in specific time duration (each 30 minutes, 5 minutes). Setting 3 is a mechanical ventilation setting, which means that none of the door and window opening were used for ventilation purposes, as same as setting 1 except using School Air –B. School Air –B is an air conditioning device, which is capable of recognizing IAQ indicators in real time, filtering and recirculating of indoor air of the space. The unit replaces the exhausted air of indoor with fresh air from outdoor if existing air has higher values according to update standard indicators value. In every setting, the objective measurements, CO2 concentration, temperature, humidity, are monitored and recorded by the below explained digital measurement devices during the class hours of studio and lecture class. Then, subjective measurements, the comfort questionnaire and performance tests of concentration and attention, were conducted in the last 20 minutes of each class hour. In each mode, the order of questions is changed and as mentioned the questionnaire conducted every other week to reduce the learning effect.

3.4. Instruments

For the thermal comfort subjective measurements, a 7-point Likert scale (-3 is for cold, and +3 is for hot) questionnaire, which is recommended by the EN ISO 10551 is used. The questionnaire includes three sections. In the first section, the demographic information of the participants is asked. In the second section, participants are asked to rate their thermal comfort level using 7-point Likert scale questionnaire. And last section divided into two tests. “To evaluation of the academic performance of student depending on air temperature, classroom air relative humidity and CO_2 concentration in three simple Gaussian correlations are developed using twelve data sets containing the concentrated (Kraepelin) and distributive (Prague) attention tests for students” (Sarbu and Pacurar, 2015). In addition, the first test is called Kraepelin test, which measures the arithmetic concentration, performance speed, and task performance accuracy. The second test called Prague test, which measures the attention of the participants on visual memories.

The digital measurement devices used to collect objective data are as follows: Laser Pyrometer, BP 21 (Infrared thermometer) from TROTEC Company,which is used in the measurement of the radiant temperature, and Flexible Thermo Anemometer, BA 15 by TROTEC Company, which is used to measure air speed, ventilation rate, and air circulation. For IAQ measurements, CO2 temp/RH Data logger CM 0019 is used, which is able to measure and monitor real time CO2 (ppm) concentration level, humidity (%) level, and temperature (°C) level by using a computer software.

4. Results

4.1. Objective measurement results

4.1.1. Studio environment

The results of the experimental measurements in the studio environment during the winter season in three ventilation modes presented that the CO2 concentration, indoor temperature and relative humidity values in mode 1 and mode 2 could not meet the demand of the recommended standards. However, in mode 3, the values were almost close to the ASHRAE Standard 62.1-2010, ASHRAE Standard 55-2010 (See Table 3). According to the experimental results of the summer season in the three ventilation modes, in the mode 1, the CO2 concentration and temperature values were above the 1000ppm, and the relative humidity levels were below the recommended levels. In the mode 2 and 3, it was clearly shown that the CO2 concentration and temperature values were not that different from each other. In addition, because of the difference between outside and inside temperature in winters compared to the difference in summers, control of temperature in the summer season was easily achieved (See Table 4).

Table 4: Objective measurement results Studio environment in both season.

		Ventilation	Outdoor T (°C)	M.R.T (°C)	Air Flow (m/s)	CO2 (ppm)	Temperature (°C)	Humidity (%)
Winter Season		Mode I	2.6	26.8	0.45	1119	28.66	26.22
	Studio	Mode II	3.1	23.8	0.5	1068	27.44	28.06
	Environment	Mode III	2.7	21.5	0.75	986	20.48	26.96
Summer Season		Mode I	30.1	25.2	0.2	1250	24.64	29.44
	Studio	Mode II	29.2	24.4	0.75	582	25.5	27.25
	Environment	Mode III	30.4	23.1	0.2	472	24.75	27.25

4.1.2. Classroom Environment

The results of the experimental measurements in the classroom environment during the winter season showed the same results as the studio environment. CO2 concentration and temperature and humidity values were not quite close to the standard recommendation in first and second mode. On the other hand, although in the third mode CO2 concentration value has reached to the acceptable value, still temperature and humidity values were problematic. The reason for that was the higher number of participants in classroom environment compared to the studio environment. In the summer season, CO2 concentration and temperature and humidity had higher values in the mode 1 compared to the second and third mode (see Table 5).

Table 5: Objective measurement results Studio environment in both season.

		Ventilation	Outdoor T (°C)	M.R.T (°C)	Air Flow (m/s)	CO2 (ppm)	Temperature (°C)	Humidity (%)
Winter Season		Mode I	-3	23.0	0.4	1472	23.23	26.14
	Classroom	Mode II	2	24.6	0.8	1031	24.13	31.24
	Environment	Mode III	3	23.3	0.25	799	25.70	26.83
Summer Season		Mode I	13	23.5	0.2	1000	24.70	31.80
	Classroom	Mode II	7	24.0	1.5	900	22.20	27.90
	Environment	Mode III	13	23.3	0.25	600	23.80	34.30

4.2. Subjective measurement results

4.2.1. Studio Environment

Among the three ventilation modes in the winter season, higher number of occupant satisfaction occurs in mode 3, mechanical ventilation. Also, the score of both performance tests were obtained only in the mechanical ventilation mode. According to previous studies higher ventilation rate has also positive influence on student performance. However, in this study, in the summer season, the student performance results in both natural and mechanical ventilation mode of all studio environments were close to each other and had higher score compared to the none ventilation mode. To further elaborate the differences between seasons, the study conducted analysis of variance (ANOVA) test. F value of 2.999 at the significant level of 0.057 was found for winter season (See table 6) and F value of 14.542 at the significant level of 0.000 for summer season (See Table 6). However, the further analysis of ANOVA with LSD test for both season have shown that there was a significant statistical difference between mode I and mode II, and between mode I and mode III, but there was not a statistical difference between mode II and III, which means that the participants' performance did not differed statistically under natural ventilation mode and mechanical school-air unit. mode.

Table 6: Oneway ANOVA results of arithmetic concentration performance (Kraepelin test) in both winter season and summer season.

(Kraepelin test) in winter season					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2463.182	2	1231.091	2.999	0.57
Within Groups	25865	63	410.56		
(Kraepelin test) in Summer season					
Between Groups	8951.62	2	4475.813	14.542	.000
Within Groups	13850.687	45	307.793		

In terms of the visual attention test (Prague test), the result of ANOVA showed statically significant differences between the seasons. F value for winter season is 9.843 at the significant level of 0.000, and for summer season 9.843 at the 0.000 significant levels (See table 7). Moreover, the difference between seasons according to LSD test results showed that in both season there was a statistically significant difference. Similar to the concentration performance results, attention performance of the participants did not differ when mode II and mode III were compared.

Table 7: One-way ANOVA result of visual attention (Prague test) both winter season and summer season.

(Prague test) in winter season					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	841.121	2	240.561	9.898	.000
Within Groups	1531.136	63	24.304		
(Prague test) in Summer season					
Between Groups	439.292	2	219.646	9.843	.000
Within Groups	1004.187	45	22.315		

4.2.2. Classroom Environment

In the classroom environment, the outcomes of ANOVA test of arithmetic concentration performance demonstrated statically significant differences between the seasons (See table 8). However, analysis of ANOVA with LSD test for both season have shown that there was a significant statistical difference between mode I and mode II, and between mode I and mode III, but there was not a statistical difference between mode II and mode III, which means that the participants concentration performance did not differed statistically under natural ventilation mode and mechanical school-air unit mode as same as the studio environment.

Table 8: Oneway ANOVA results of arithmetic concentration performance, (Kraepelin test) both winter season and summer season.

	Sum of Squares	df	Mean Square	F	Sig.
(Kraepelin test) in winter season					
Between Groups	73034.087	2	36517.043	19.399	.000
Within Groups	559081.710	297	1882.43		
(Kraepelin test) in Summer season					
Between Groups	43231.293	2	21615.647	22.503	.000
Within Groups	141202	147	960.558		

The ANOVA results of the Visual Attention Test (Prague test) showed statistically significant difference between groups (See table 9). Moreover, the difference between groups according to LSD test results showed that in winter season there was a statistically significant difference between groups. Similar to the concentration performance results, attention performance of the participants did not differ when mode II and mode III were compared. However, summer season had the different results on LSD test; there was a significant statistical difference between mode I and mode III, whereas there was not a statistical difference between mode I and II, and mode II and III.

Table 9: One-way ANOVA result of visual attention (Prague test) both winter season and summer season.

	Sum of Squares	df	Mean Square	F	Sig.
(Prague test) in winter season					
Between Groups	1517.007	2	758.503	16.978	.000
Within Groups	13269.030	297	44.677		
(Prague test) in Summer season					
Between Groups	275.080	2	137.540	2.912	.058
Within Groups	6943.880	147	47.237		

5. Discussion

This paper aims to analyze measurements of thermal comfort and IAQ in different ventilation modes of design studio and classroom. It investigated the relationship between student performance and CO2 concentration values to enhance performance of students. According to a study in the US, “during the hot season, outdoors temperature is a good predictor of indoor temperature conditions” (Nguyen, 2014). This research is in the same line with the study by showing results that during summer season there is not a significant difference between mode 2 and mode 3 in terms of both occupant’s satisfaction and performance; however, mode 1 still has lowest rank between the groups (table 2,3,4, and 5 demonstrated the overall CO2 concentration values). On the other hand, during the winter season, it was observed a significant difference between the results gathered from the three modes. The graph (see Figures 6 and 7) showed a linear increasing rank from mode 1 to mode 3 in terms of thermal comfort and student performance.

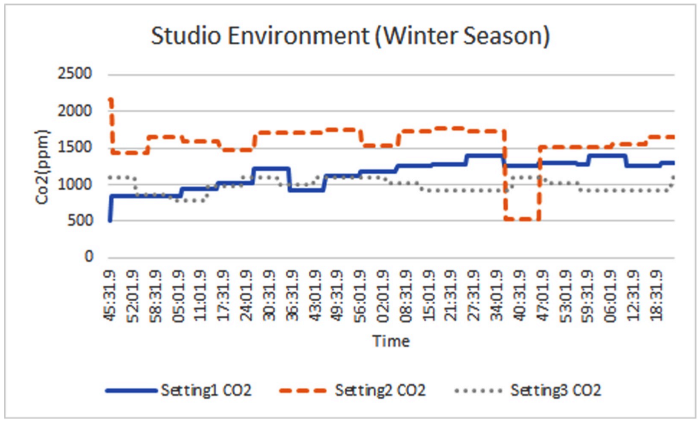

Figure 2: Variation of mean CO2 concentration of studio environment in the three settings, in winter season.

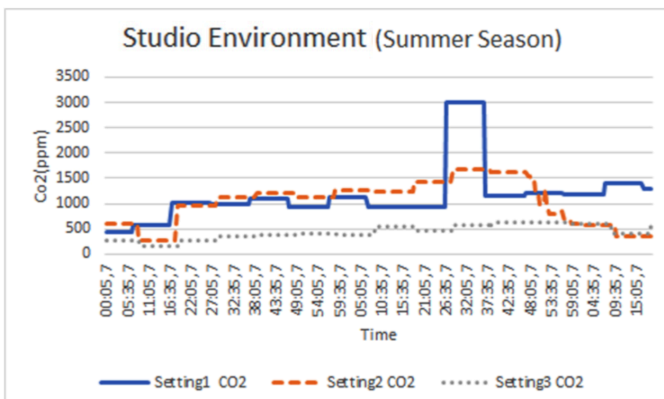

Figure 3: Variation of mean CO2 concentration of studio environment in the three settings, in summer season.

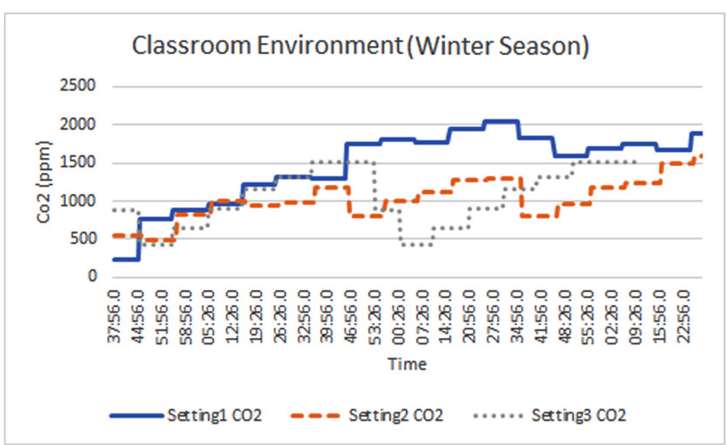

Figure 4: Variation of mean CO2 concentration of classroom environment in the three settings,

in winter season.

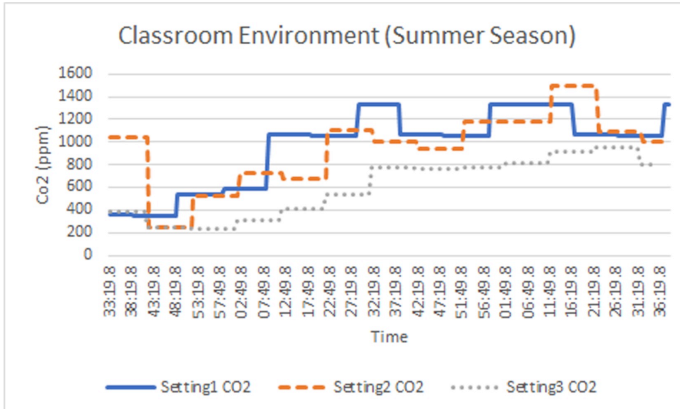

Figure 5: Variation of mean CO2 concentration of classroom environment in the three settings, in summer season.

In addition, according to the study by Sarbu and Pacurar (2015), indoor ventilation was not only significant in terms of decreasing the risk of health problems within learning environments, but also significant in terms of eliminating any negative effects on learning and productivity. Therefore, it can be said that when the highest ventilation rate occurred in both subjective and objective measurement results, students should have higher concentration and attention performance results. Thus, in the study it was obvious that in the summer season the test results have close mean objective and subjective values in both natural ventilation mode and mechanical ventilation mode.

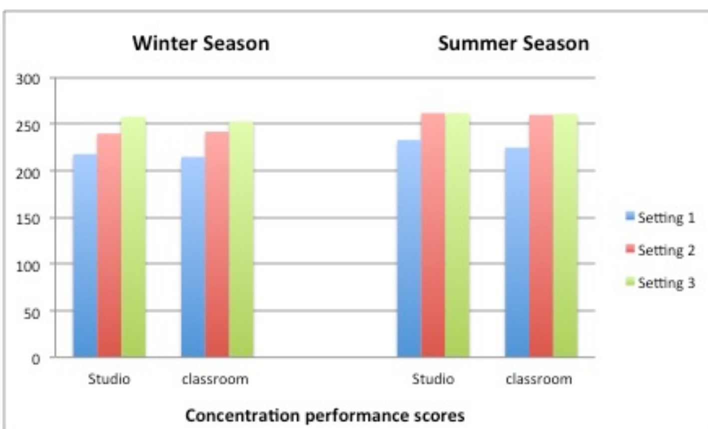

Figure 6: The comparison of concentration performance scores in both studio and classroom environment, regarding to the both winter and summer season.

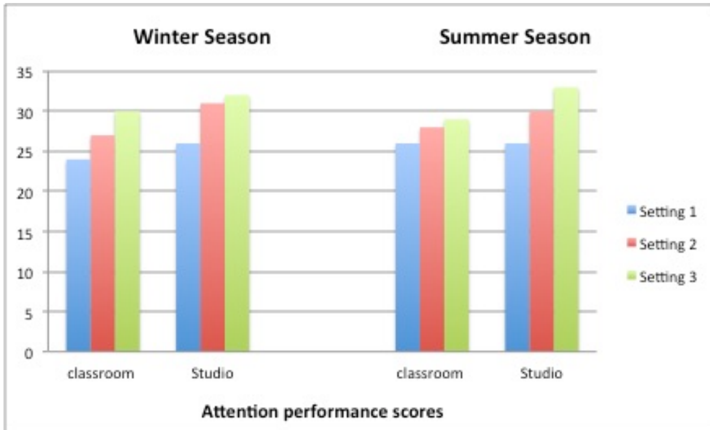

Figure 7: The comparison of attention performance scores in both studio and classroom environment, regarding to the both winter and summer season.

6. Conclusion

People spend more than 80% of their time in indoor environments, such as in schools, offices, and shops. Schools are the places, where most of the young population spends their daytime. Thus, "university environments are the most crucial indoor environments to ensure student's health, effective learning and well-being (Silvers, 1994; Diapouli, 2008; Dorizas, 2013). This paper investigated the effects of different ventilation modes on students' performance. It measured experimentally the thermal comfort and IAQ of both a design studio and classroom environment and under three different ventilation modes. The experimental results were in parallel with the literature review. As mentioned in the literature review, the study by Wargocki & Wyon (2008) showed that increasing outdoor air supply enhance the student performance on numerical and language-based task, also the percentage of error on numerical task significantly reduced in that case. Moreover, according to the subjective outcomes of the study, both the studio and classroom environment with TROX school-air unit had highest performance scores compared to other two ventilation modes. In the absence of a mechanical air-conditioning system, the performance decreased in both environments and seasons. On the other hand, studio environment had a slight difference on survey and experimental measurements' results because studio environment has low population density with high spending time on studio environment, which makes balance on CO2 and temperature values with high population density with the low spending hours of classroom environment.

The study has the following limitations, such as using the same room in all measurements; not having the equal number of male and female participants. Moreover, conducting the study in various studios at the same time period with higher participants number can feed the study in a more different way. Future studies should focus on sustainable strategies because providing better thermal and air quality conditions in classrooms would be cost-effective, developing sustainable strategies becomes essential.

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